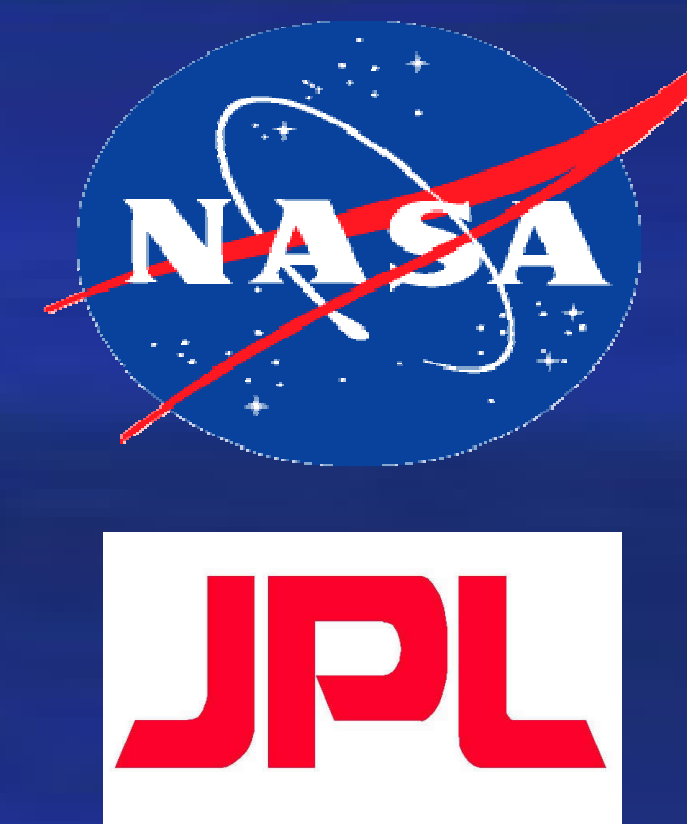


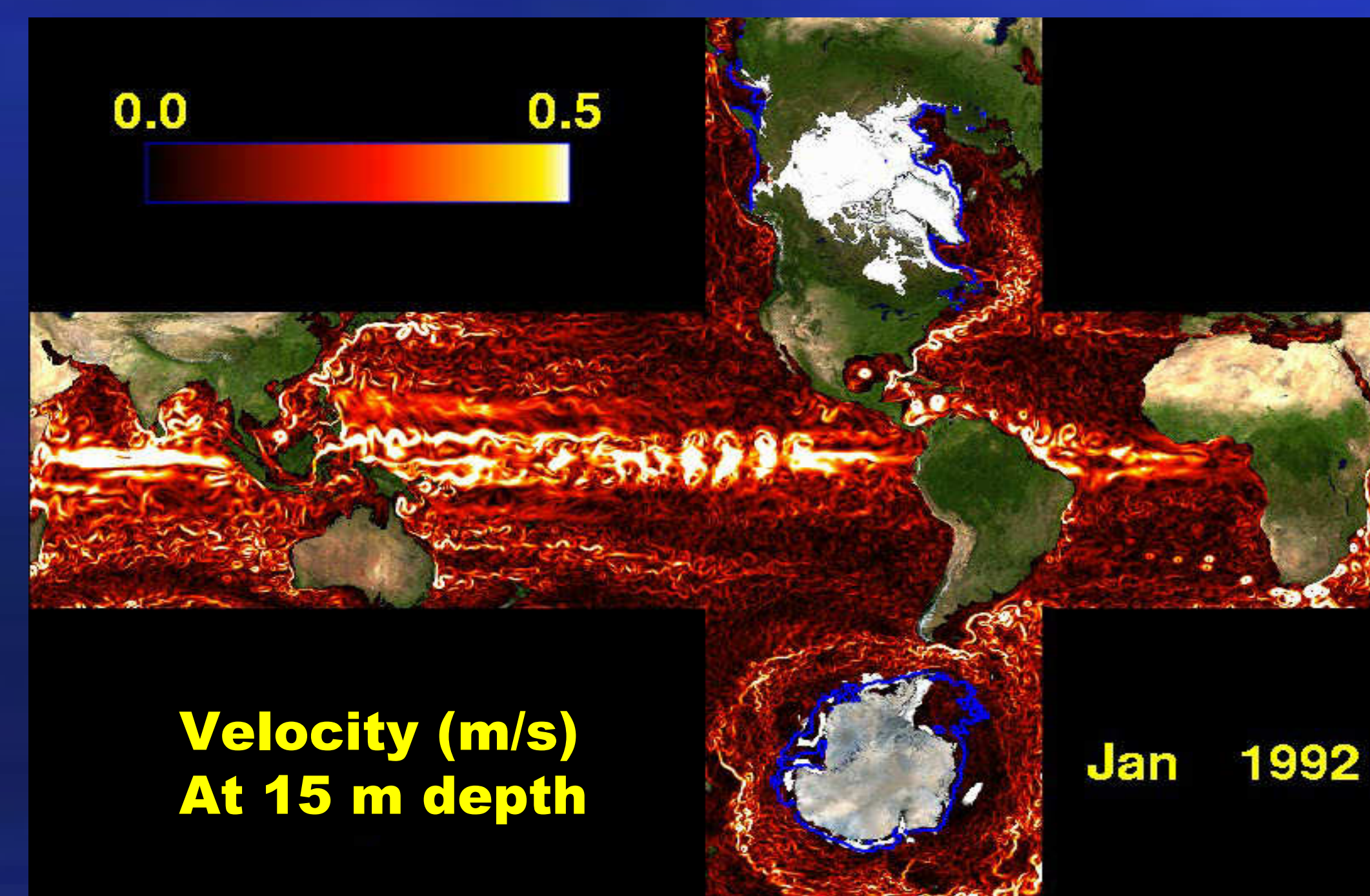
# Assessment of the ECCO2 Regional Optimized Solution in the Arctic

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## 1. Introduction:

The Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2) project aims to produce increasingly accurate, physically consistent, time-evolving syntheses of most available global-ocean and sea-ice data at resolutions that start to resolve ocean eddies and other narrow current systems. ECCO2 syntheses are obtained by least squares fit of a global full-depth-ocean and sea-ice configuration of the Massachusetts Institute of Technology general circulation model (MITgcm) to the available data. This study is a continuation of previous work in Nguyen et al., [2008] where we assessed the ECCO2 optimized regional Arctic Ocean solution. The model's ability to produce and maintain the Atlantic Water and Pacific Water and the cold halocline is discussed. For sea-ice, we assess the model ability to reproduce the recent summer sea-ice extent minimum in 2007.



## 2. ECCO2 Model Configuration:

### Ocean model:

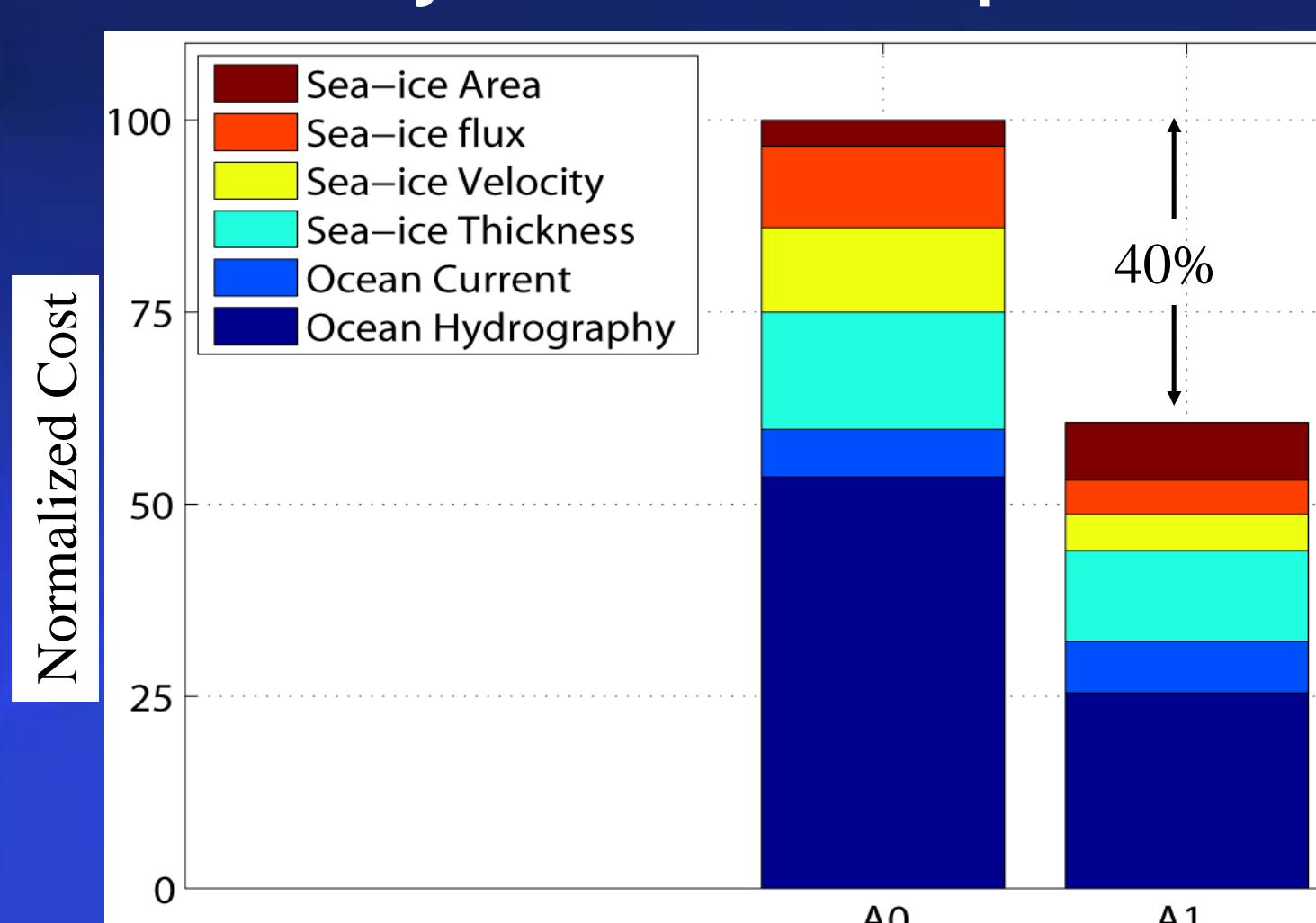
- 18-km horizontal grid spacing
- 50 vertical levels
- volume-conserving, C-grid
- bathymetry: S2004 blend of GEBCO and Smith and Sandwell [1997]
- KPP mixing [Large et al., 1994]
- ECMWF/ERA-40 forcings
- WOA05 initial conditions

### Sea-ice model:

- C-grid
- 2-category zero-layer thermodynamics [Hibler, 1980]
- Viscous plastic dynamics [Hibler, 1979]
- Prognostic snow and sea-ice salinity
- PHC sea-ice initial conditions

## 3. Optimized Solutions:

- A0:** 1992-2006 global solution: optimized based on a Green's functions approach and a set of 70+ sensitivity experiments.
- A1:** 1992-2007 regional optimization using all available sea-ice velocity and ocean temperature & salinity data for the Arctic.



**Fig 3-1: Total Cost Reduction**  
Total cost normalized by cost from experiment A0. Cost is defined as the squared distance in Model minus Data misfits. The largest cost reduction is in ocean hydrography and sea-ice velocity / fluxes. Detailed analyses of sea-ice velocity and fluxes, and ocean hydrography are presented in this paper.

## 4. Data:

### I. Sea-ice

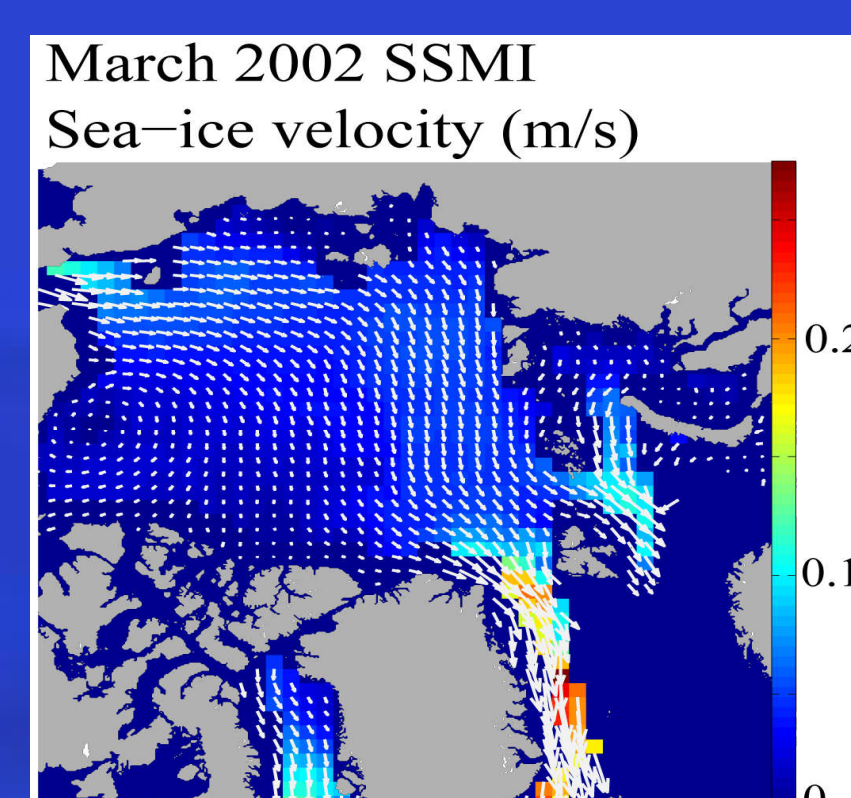
- Fluxes: [Kwok, 2004, 2006]
- Velocity: Passive microwave [http://www-radar.jpl.nasa.gov/rpss/ice\_motion\_3.html]
- Extent / Concentration: Special Sensor Microwave Imager (SSM/I) daily average [http://www.nsidc.org]

### II. Ocean Hydrography

- Conductivity-Temperature-Depth (CTD) profiles: AWI Polarstern Expeditions (PANGAEA), Arctic-Subarctic Ocean Flux Array for European Climate North (ASOF-N), SCICEX [http://boreas.coas.oregonstate.edu/scicex/scicex.html], Beaufort Gyre Exploration Project (BGEF) [http://www.whoi.edu/beaufortgyre/]

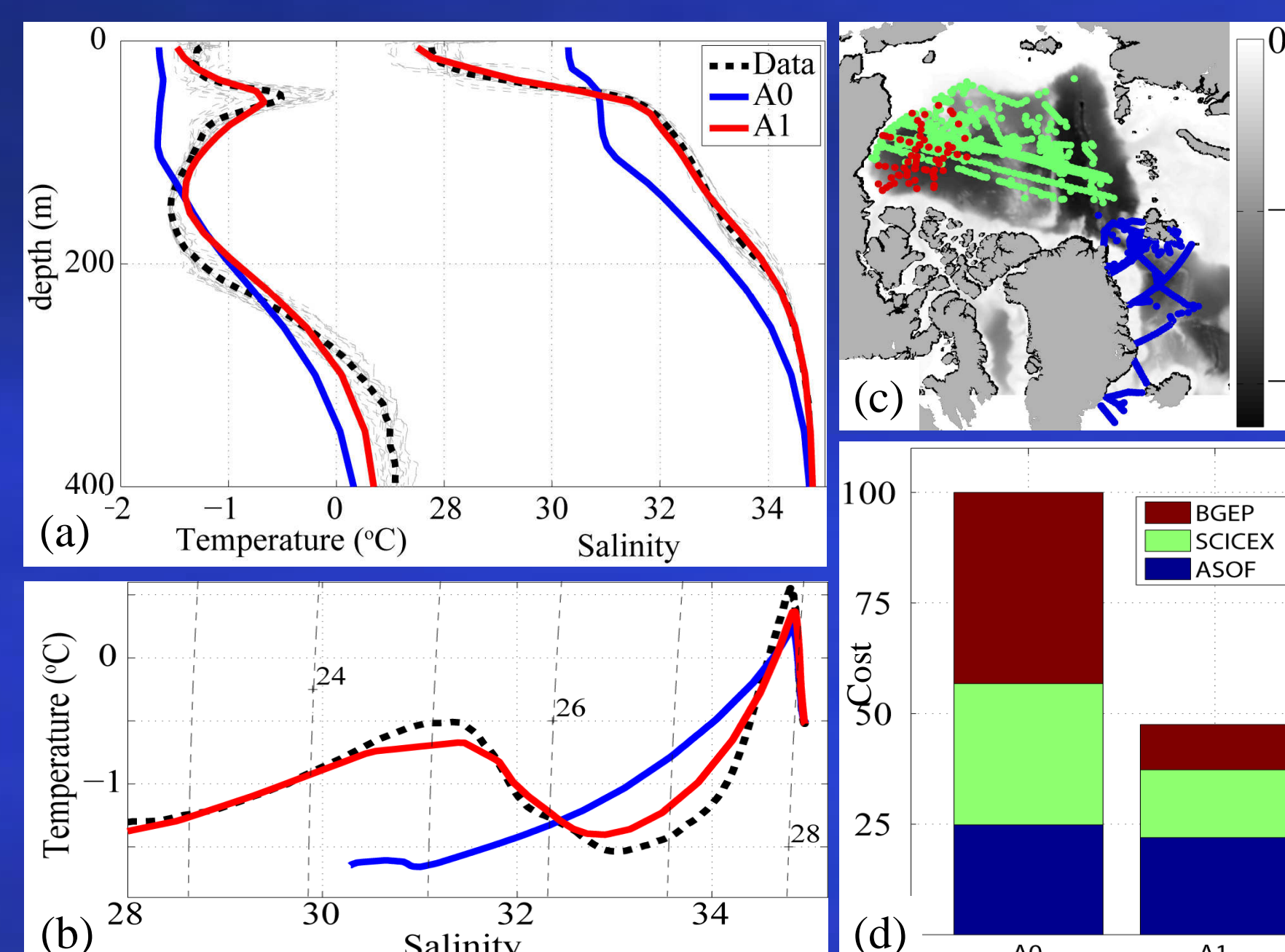
### III. Integrated

- Bering Strait fluxes: Moorings [Woodgate, 2004]
- Heat budget / fluxes: Moorings, ASOF-N, [Woodgate, 2005, Schauer, 2004]



**Fig 4-1: Distribution of sea-ice velocity data.**

## Hydrography



**Fig 6-1: CTD profiles**

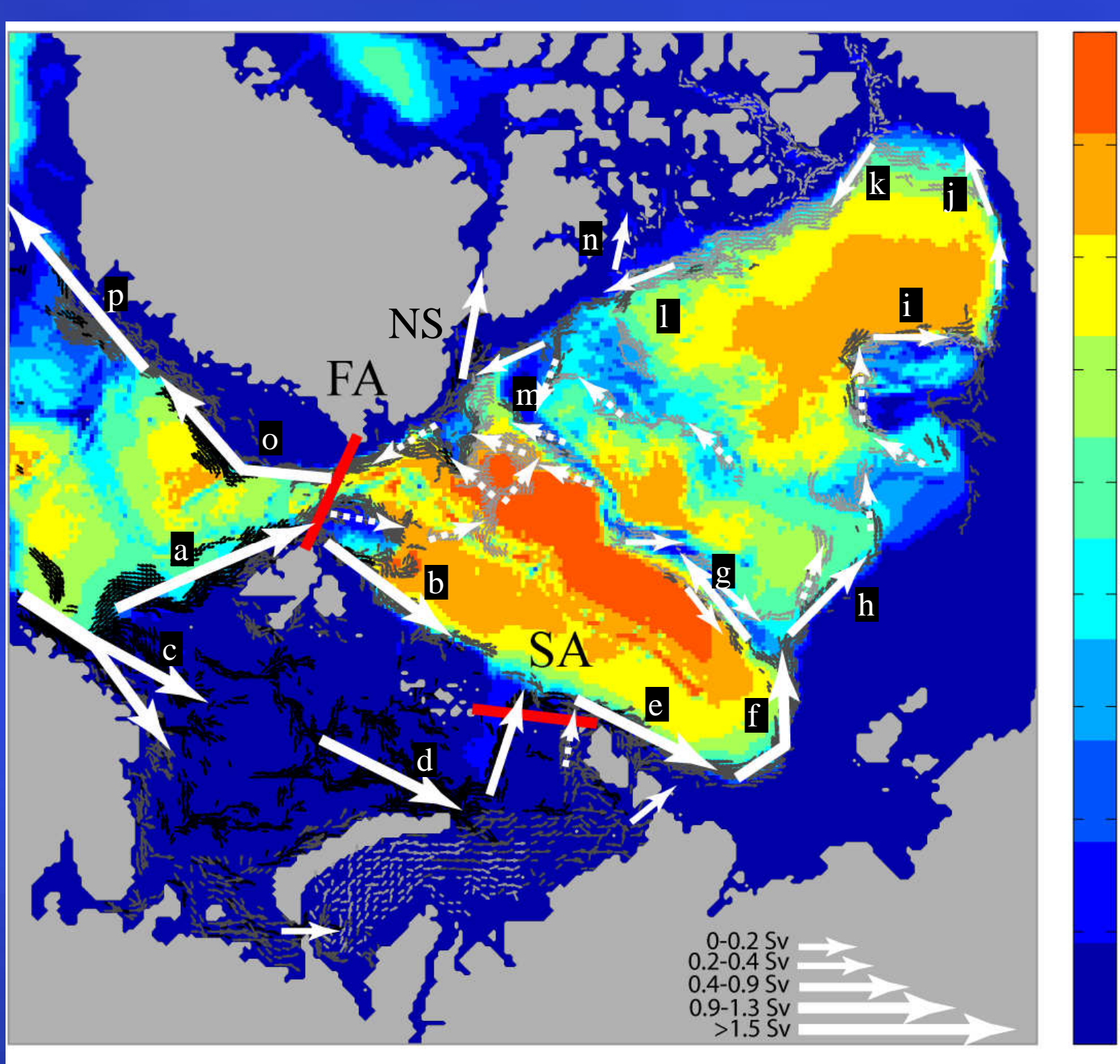
(a-b) Vertical temperature and salinity profiles and T/S diagram in the Canadian Basin in August 2003. Data are from BGEF. In (a), individual data profiles are shown in light gray with data mean shown in heavy dashed black line. Contours in (b) are density anomalies. With a brine-rejection scheme, the halocline is reproduced in solution A1 [Nguyen et al., 2008b].

(c) Distribution of BGEF (2003-2004), SCICEX (1993-2000) and ASOF (1997-2004) CTD data used in this assessment.

(d) Total cost normalized by A0 cost. Cost is calculated as the squared distance of the Model minus Data misfits. The overall reduction in misfits is greater than 50% in solution A1 compared to A0. Improvements are both spatial and temporal.

## 6. Arctic Ocean Assessment [1992-2006]:

### Circulation – Atlantic Water (AW)



**Fig 6-2: Atlantic Water**

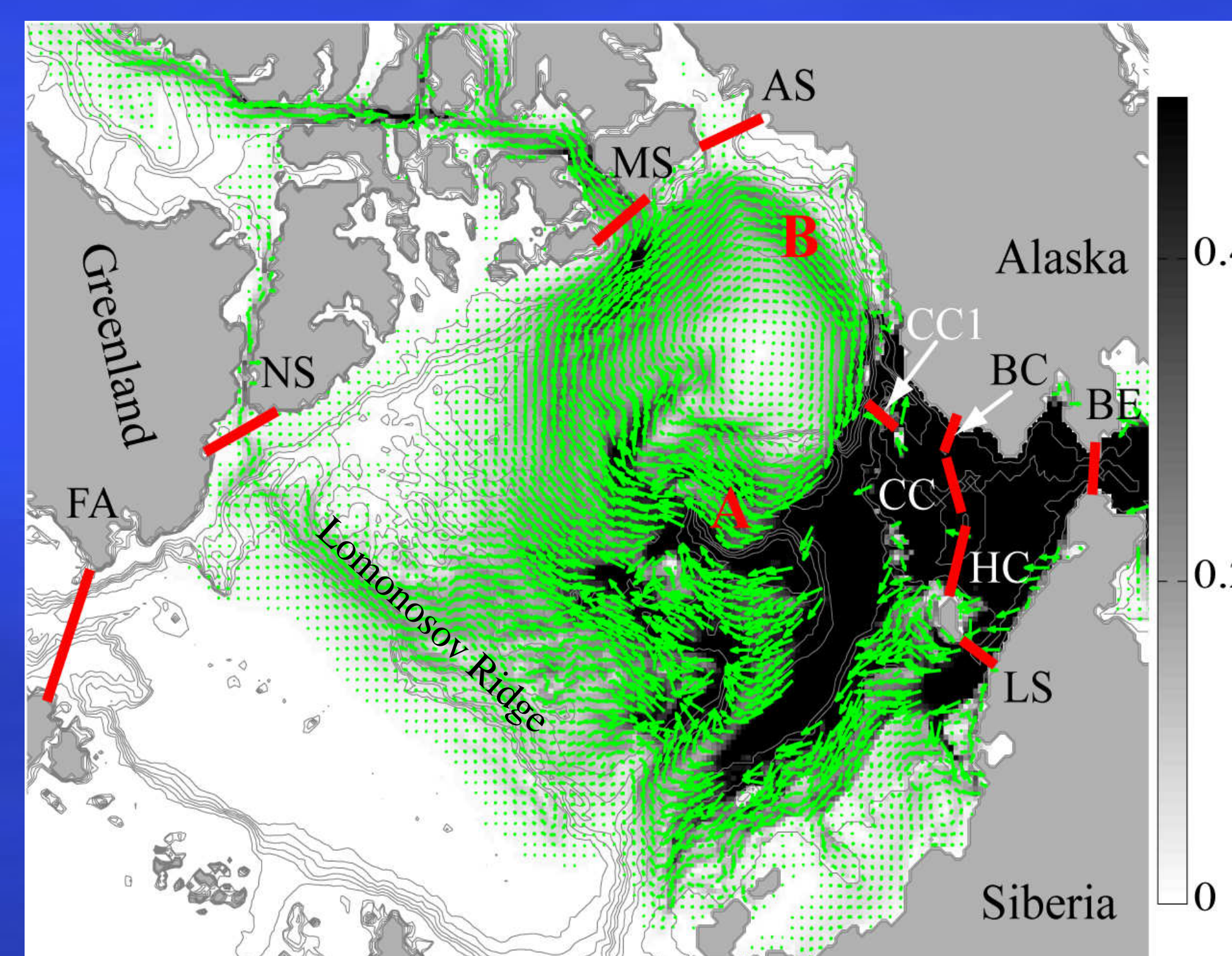
16-year mean Atlantic Water rim currents in the Arctic from solution A1. Background color shows bathymetry in km. Small arrows represent velocity magnitudes ( $|u| > 0.03$  m/s in black,  $0.01 < |u| < 0.03$  m/s in dark gray, and  $0.003 < |u| < 0.01$  m/s in light gray). Large white solid arrows show total Atlantic Water transports along paths a  $\rightarrow$  p as per scale provided in the legend (see also Table 1). Large dashed white arrows are inferred transports based on current strengths. The thick red lines denote the Fram Strait (FA) and the St Ana Trough (SA).

### Discussion:

- Transports across FA and SA smaller than observations [Schauer, 2004] and high-resolution numerical model in the Barents Sea [Maslowski [2004]
- Comparable volume transports across FA and SA
- Cyclonic rim currents along Eurasian, Makarov, and Canadian Basins
- Positive topostrophy in the entire Arctic Ocean, consistent with Holloway [2007]
- Barents Sea: largest heat loss of  $\sim 40$  TW (see Table 1)  $\rightarrow$  cold water entering the Arctic across SA
- more than 80% of AW passing point (f) continues along (h)
- High heat content in the Canadian Basin (i to l): Pacific Water (PW) source
- Freshening in the Canadian Basin (compare point h to i through l): due to mixing with Pacific Water

Table 1 : Atlantic Water Transport				
Gate	Vol (Sv)	Heat (TW)	Salt ( $10^{16}$ kg/s)	Comment
a	1.6	12	57	
b	1	6.6	37	
c	2	40	70	
d	1.2	-0.08	44	Barents Sea
SA	0.71	-1.08	25	
e	1.2	3.4	42	
f	0.98	2	35	Eurasian path
g	0.43	15	0.9	
h	0.82	1.7	29	
i	0.34	12	0.5	
j	0.34	12	0.45	Amerasian path
k	0.24	8.4	0.27	
l	0.34	12.3	0.4	
m	0.28	9.9	0.4	
n	0.19	-0.3	6.6	
NS	0.63	-2.7	21.3	export
p	3.5	126	16	Greenland sea

### Circulation – Pacific Water (PW)

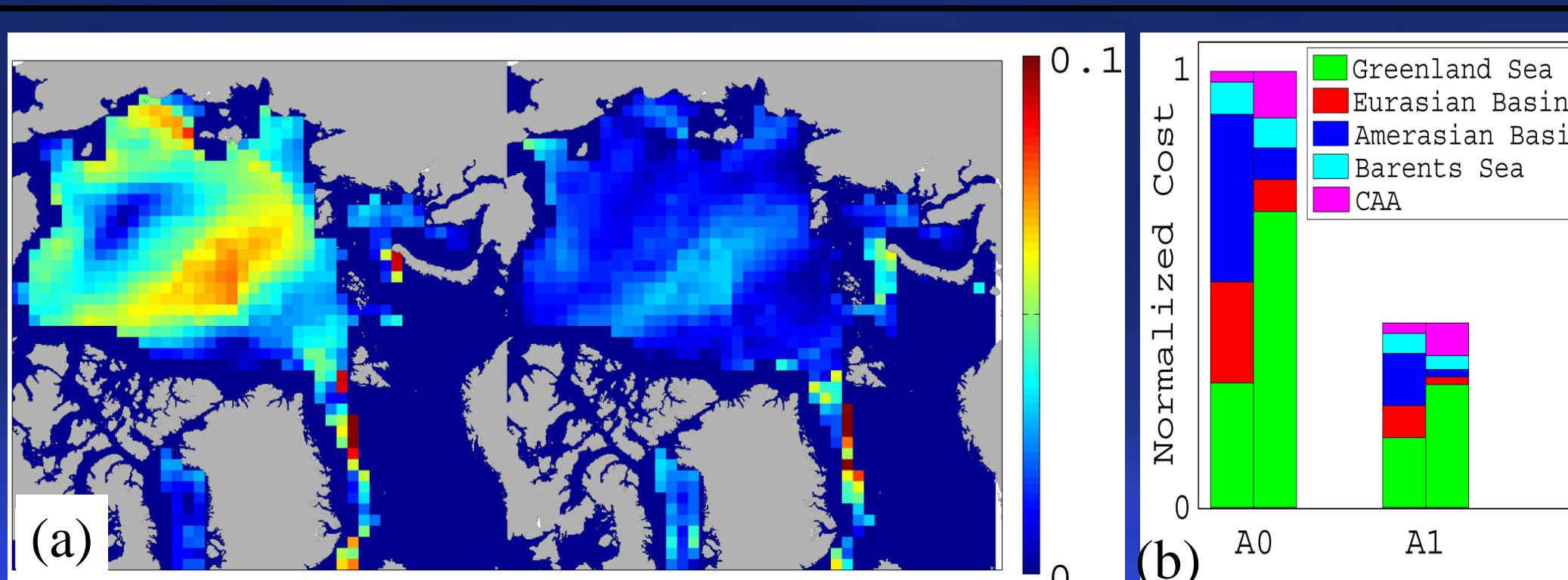


**Fig 6-3: Pacific Water**

Upper 100-m Pacific Water mean flow in the Arctic Ocean obtained from passive tracers. Contours are bottom topography. Background color shows approximate strength of the passive tracers. Only velocities in areas with tracer concentration  $< 0.3$  are shown (green arrows). Vector lengths scale with tracer concentration and not with flow strength. Transports as calculated using full the velocity field are shown in Table 2.

## 5. Sea-ice Assessment [1992-2007]:

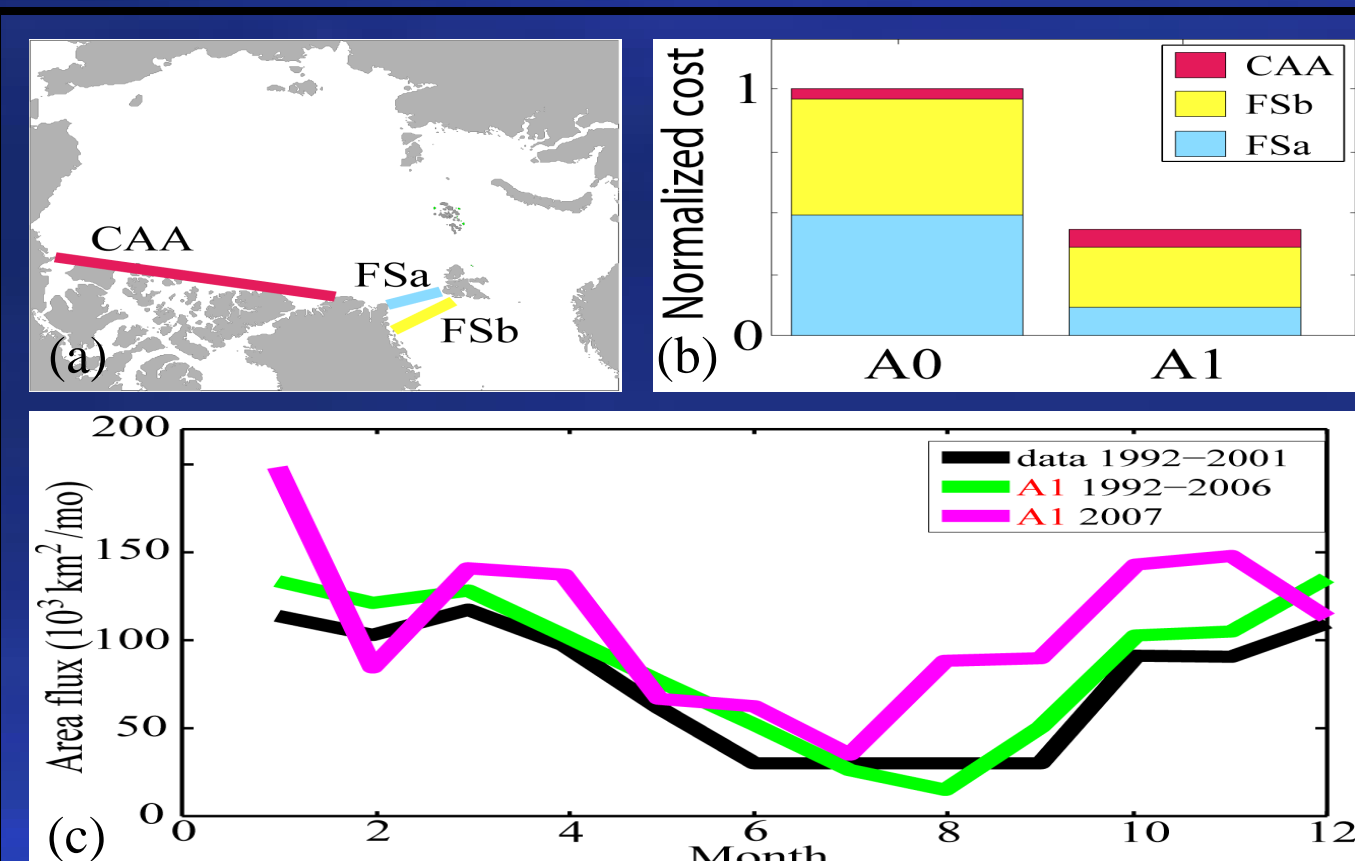
### Sea-ice Velocity



**Fig 5-1: Sea-ice Velocity**

Model-Data residuals between solutions A0 and SSMI-derived sea-ice velocity (a, left panel) and between A1 and data (a, right panel). The total reduction in misfits between Model and Data is shown in (b). For each solution in (b), the left stacked bar shows the absolute contribution of each region in the Arctic to the total misfits and the right stacked bar shows contributions weighted by the length of the data in each region. The optimization yields  $> 50\%$  reduction in misfits (b).

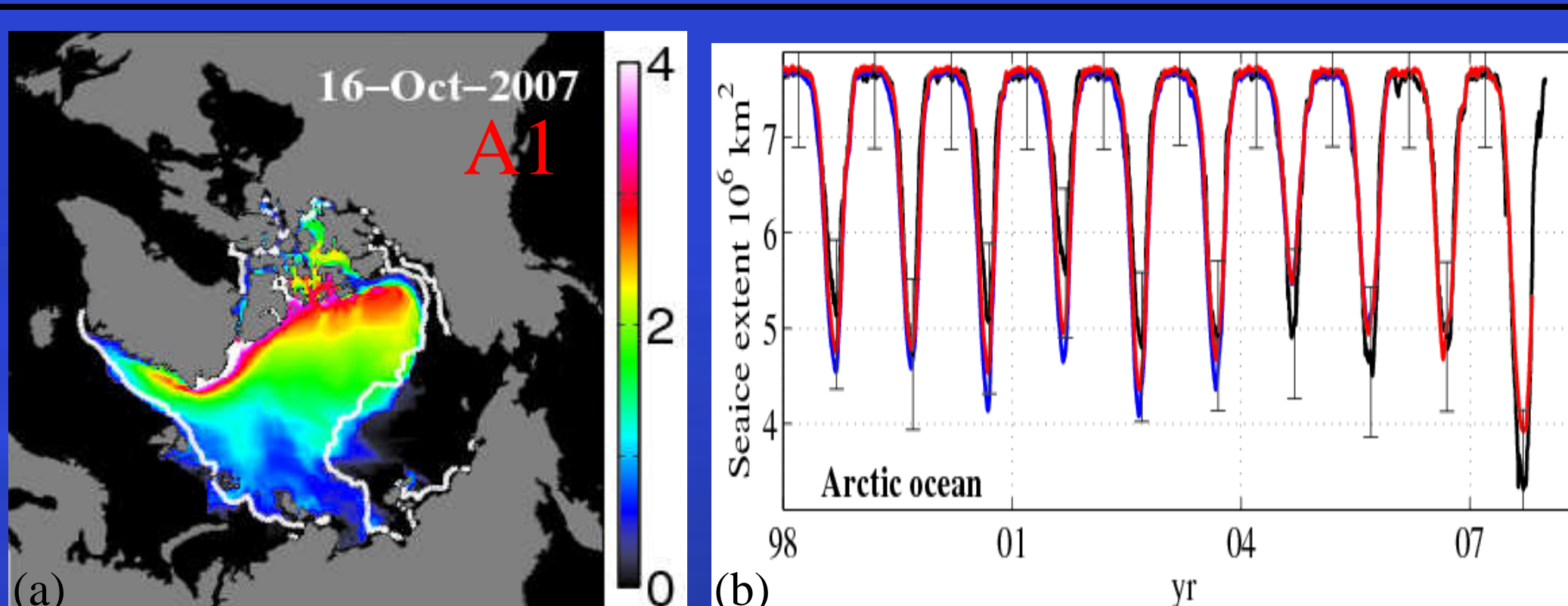
### Sea-ice Transports



**Fig 5-2:**

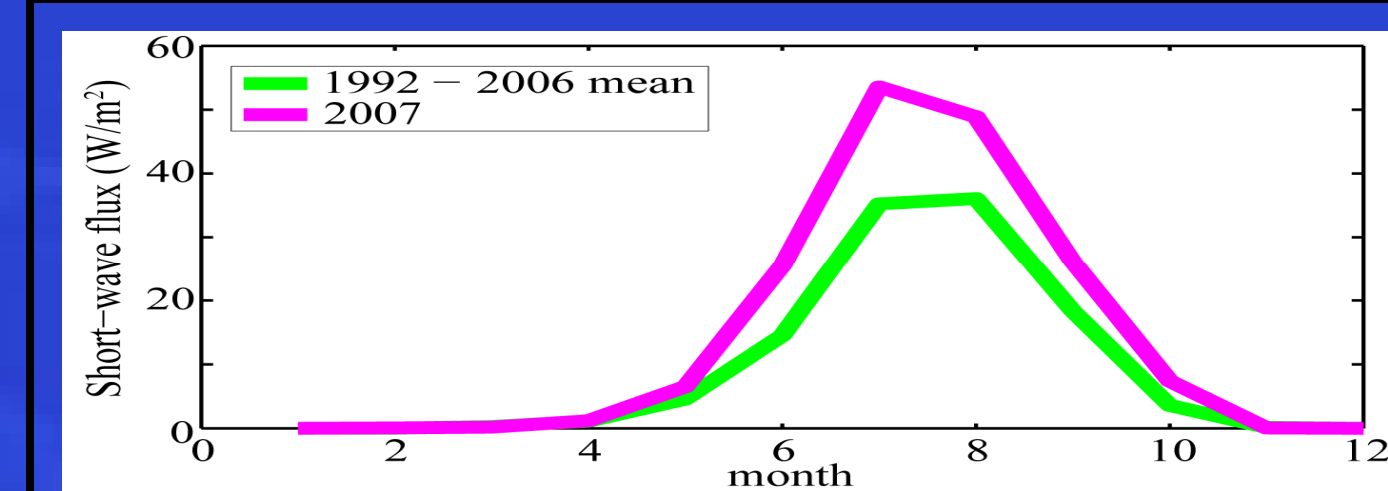
(a-b) Total reduction of ice exports across all gates in the Arctic. In (c) A1's area ice flux across Fram Strait in 2007 is compared to A1's 16-year mean and SSMI-derived 10-year mean. Exports over the 2007 summer months are higher than the 16-year mean.

### Sea-ice extent



**Fig 5-3:** (a) Map of sea-ice thickness during the 2007 sea-ice minimum for solution A1, and (b) time-series of sea-ice extent from 1998-2007. White contour line in (a) shows SSMI sea-ice extent. As seen in (b), both solutions A0 (blue) and A1 (red) reproduce well the seasonal cycle of sea-ice extent in SSMI data (black). A1 reproduces more realistic minimum sea-ice extent in the summer compared to A0 (b). Error bars in (b) show the 10% uncertainties in sea-ice extent from SSMI estimates.

### The 2007 sea-ice minimum



**Fig 5-4:**

Net short-wave radiation in the Amerasian Basin in 2007 compared to 16-year mean. Perovich [2008] showed that in the Beaufort Sea, increased open-water resulted in increased solar heat input into the ocean and  $> 100\%$  increase in sea-ice bottom melting. Zhang et al., [2008] suggested that  $\sim 70\%$  of the additional ice loss in the Arctic in 2007 is due to this increase in solar input. As shown in Fig 5-2 above, some of the ice loss is due to increased sea-ice export.

### Discussion:

- Pacific Water: reaches the interior via: Herald Canyon (HC), Central Canyon (CC), Barrow Canyon (BC)
- $\sim 10\%$  flows across Long Strait, continues along the Siberian Coast
- Transports comparable with both high resolution Chukchi Sea numerical model estimates [Spall, 2007] and observations [Woodgate, 2005]
- Flow along BC splits with 90% crossing gate CC1 and merging with the flow across CC to become part of the Beaufort Gyre circulation.
- Largest export in Canadian Archipelago: across McClure Strait (MS).
- Water crossing HC  $\rightarrow$  splits into 2 branches:
  - 1) joining CC flow at A along the Beaufort Gyre circulation
  - 2) flowing along bathymetry contours off of Siberia, then along Lomonosov Ridge out to Nares Strait (NS) and Fram Strait (FA).
- Residence time:  $\sim 1$  yr to cross Chukchi Sea (point A),  $\sim 4$  yr to reach MS (along Beaufort Gyre circulation), 4-5 yr to reach point B, 7 yr to reach NS, 8yr to reach FA.

**Table 2 : Pacific Water Transport (Sv)**

Gate	A1	Spall [2007]	Woodgate [2005]
BE	0.78	0.8	$0.8 \pm 0.2$
LS	0.13		$0.18 \pm 0.12$
HC	0.32	0.4	$0.28 \pm 0.12$
CC	0.22	0.2	-0.2
BC	0.25	0.2	$0.16 \pm 0.07$
CC1	0.48*		
AS	0.07		
MS	0.29		
CAA	0.09		
NS	0.13		
FA	--		

## 7. Summary and Ongoing Work:

The optimized ECCO2 Arctic solution reduces model-data misfits by 40%

### Sea-ice:

- The 2007 sea-ice minimum, a result of increased ice meltings and exports, is well reproduced.
- Sea-ice exports across Fram Strait match with observations from Kwok [2004]

### Ocean:

- A brine rejection scheme is used to reproduce a realistic cold Halocline in the Canadian Basin
- Atlantic and Pacific Water masses are well reproduced
- Pacific Water transports: consistent with previous observations and high-resolution numerical model
- Atlantic Water volume fluxes: lower than observed However the cyclonic rim currents are well reproduced and has positive topostrophy in all basins.

We are currently working on improving the representation of water masses in the Greenland Sea to produce more realistic transports at Fram Strait.

### Acknowledgments:

ECCO2 is a contribution to the NASA Modeling, Analysis, and Prediction (MAP) program. We gratefully acknowledge computational resources and support from the NASA Advanced Supercomputing (NAS) Division and from the JPL Supercomputing and Visualization Facility (SVF).

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